

**EDGEWOOD ARSENAL
TECHNICAL REPORT**

EATR 4639

EVALUATION OF A POWER-ASSISTED BREATHING DEVICE

I. AIRFLOW CHARACTERISTICS

II. SUBJECTIVE PREFERENCE FOR AIRFLOWS OVER THE FACE

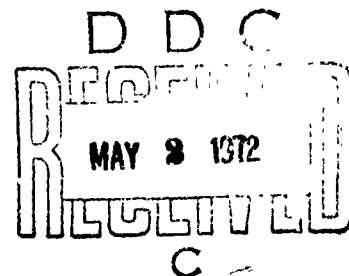
by

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April 1972



**DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
Biomedical Laboratory
Edgewood Arsenal, Maryland 21010**

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**EVALUATION OF A POWER-ASSISTED BREATHING DEVICE
PART I. AIRFLOW CHARACTERISTICS
PART II. SUBJECTIVE PREFERENCE FOR AIRFLOWS OVER THE FACE**

by

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Medical Research Division

April 1972

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Task 1W662710AD2501

**DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
Biomedical Laboratory
Edgewood Arsenal, Maryland 21010**

FOREWORD

The work described in this report was authorized under Task 1W662710AD2501, Medical Defense Against Chemical Agents/Biomedical Evaluation of Protective Material. The data were collected in March and April 1971.

The volunteers in these tests are enlisted US Army personnel. These tests are governed by the principles, policies, and rules for medical volunteers as established in AR 70-25.

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DIGEST

The power-assisted breathing device was conceived to reduce protective mask inspiratory resistance. This device consisted of a battery-operated blower attached to the inspiratory ports of the M17A1 mask, which was designed for continuous operation during wear. It supplied a flow of air through filters at 56 liters/min; this flow varied during wear with the phase of breathing. Inspiratory resistance was reduced by 30 mm H₂O at 86 liters/min (the standard flow for measuring static resistance), whereas expiratory resistance was increased by 12 mm H₂O.

Subjective preferences for airflows over the face were tested from 75 to 250 liters/min for design information. Subjective complaints developed with room temperature airflows above 100 liters/min and involved difficult expiration and discomfort around the eyes.

It is probable that any beneficial effects of this power-assist system would be counterbalanced by the added weight and the expiratory resistance. This was substantiated by the results of treadmill performance tests, which are the subject of a separate report.

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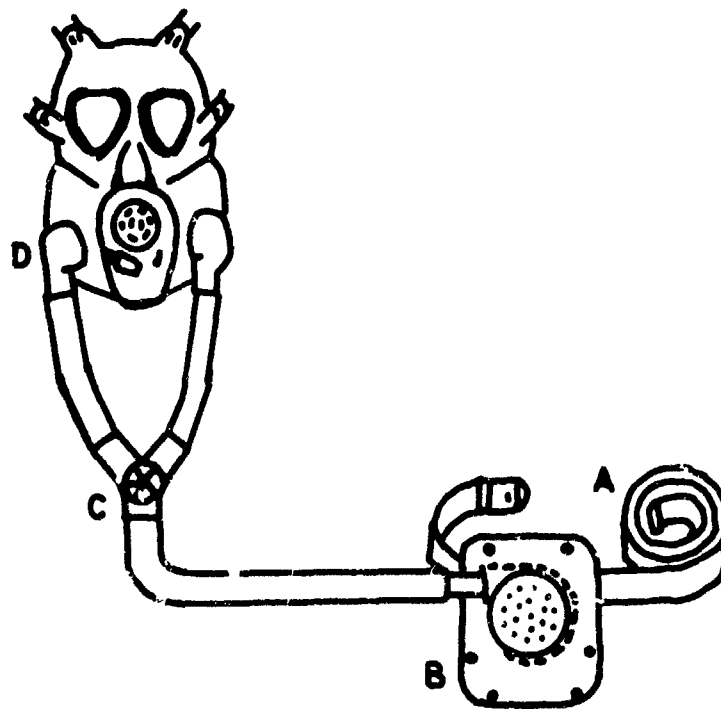
EVALUATION OF A POWER-ASSISTED BREATHING DEVICE*
PART I. AIRFLOW CHARACTERISTICS
PART II. SUBJECTIVE PREFERENCE FOR AIRFLOWS OVER THE FACE

I. INTRODUCTION.

In response to attempts at improving the protective mask, the concept of a powered, air-filtered, respiratory device was developed. In its present form it is called a power-assisted device. This concept has the possibility of reducing inspiratory resistance and discomfort from heat in protective masks. In addition, this airflow could possibly be used for evaporative cooling if directed over large skin surface areas at appropriate airflows.

A. Description of Power-Assisted Mask.

An M17A1 protective mask was connected to a battery-supplied blower that was developed at the Harvard School of Public Health by Professor W. Burgess (contract DAAA-15-70-C-0091) to supply air over the head and face of coke-oven workers. This blower was carried on the hip of a subject and was connected to the protective mask by flexible, corrugated tubing 23 mm in diameter. A Y-tube with an inspiratory valve attached directed air to each inspiratory opening of the mask. Molded rubber adapters connected the tubing to the inspiratory ports of the mask (figure 1).



A BELT
B POWER ASSIST UNIT
C Y WITH INSPIRATORY VALVE
D ADAPTERS

Figure 1. The Power-Assisted Concept

* a part of this research, titled "Evaluation of a Power-Assisted Breathing Device--Part III Treadmill Work Performance," by S. Jackson and E. G. Cummings is being published as a separate report

B. Background.

The nearest specific relative to the power-assist concept is the E26 tank collective protector connected to the E56 protective mask.¹ This unit supplied filtered air to the mask at a continuous flow of 3 to 4 cfm and was worn by crewmen for 2 to 4 hours per day. It had a physiological disadvantage in that men objected to the continuous flow of air blowing on their necks through the outlet valve, and it was suspected that it would perform poorly in cold weather. The basic idea is similar to the concept of the ventilated suit,² which has evolved over the years to a self-contained unit supplying filtered air for breathing and heat regulation.³

The capability of a power-assisted system to provide evaporative cooling in the heat is limited by the exposed surface area and flow and humidity of the cooling air. In view of the requirements established by Craig,² the surface area under a mask, about 3% to 3.5% of the body surface total,⁴ would be inadequate for a measurable total-body cooling effect.

II. PART I, AIRFLOW CHARACTERISTICS.

A. Purpose.

These tests were designed to describe the respiratory flow and pressure characteristics of the power-assisted system.

B. Materials and Methods.

Mask pressure was measured from inside the nosecup by connecting a #13 hypodermic needle, modified as a manifold sampler, to a 0- to 1-psi strain gage with 8 feet of 3-mm-ID plastic tubing. Inspiratory and expiratory airflow were measured by a screen pneumotachometer connected with 8 feet of 3-mm-ID plastic tubing to a 0.05-psi strain gage. To measure inspiratory airflow, the pneumotachometer was placed in the inspiratory line at a point between C and D, as shown in figure 1. Subsequently, the same pneumotachometer was connected to the expiratory valve and was used to measure expiratory airflow.

One subject wore the power-assist mask and performed treadmill exercise and breath-holding maneuvers to provide a range of airflow recordings. Recordings were made during breathing with the blower off, with the blower on, and during breath-holding with the blower on. This technique of measuring resistance during breathing is sometimes called the dynamic resistance method.

C. Results.

The power-assist unit with its filter pad removed was able to develop an airflow of 184 liters/min (6.5 cfm) as measured by screen pneumotachometer. When the resistance of the mask filters was placed in series with it, the unit supplied a constant inspiratory flow of 56 liters/min during a breath hold. This latter flow was accompanied by a positive internal mask pressure of 14 mm H₂O.

¹Martin, R. E. CRLR 43. Operational Tests of Tank Collective Protector, E26 at Aberdeen Proving Ground. March 1953. UNCLASSIFIED Report.

²Craig, F. N. MDRR 5. Ventilation Requirements for an Impermeable Protective Suit. April 1950. UNCLASSIFIED Report.

³Graf, C. H., Cummings, E. G., Blevins, W. V., Bulette, C. R., and Oberst, F. W. EATM 100-7. PS Leakage Tests on the Chemical Protective Clothing for Explosive Ordnance Disposal Personnel. June 1970. UNCLASSIFIED Report

⁴Lund, C. C. and Browder, W. C. The Estimation of Areas of Burns. Surg. Gyn. Obs. 79, 352-358 (1944)

During breathing, the flow supplied by the blower varied. One indication was the sound of the motor, which could be heard to alternately speed up and slow down. During breathing at rest, an expiration reduced the power-assisted flow from 56 liters/min to 38 liters/min for 0.2 second of each breath. During forced breathing, which simulated exercise, expiration reduced the power-assisted flow to 18 liters/min for 0.2 second of each breath. At all inspirations with peak flows of less than 56 liters/min, the air supplied by the blower goes into the lungs, so that no recording of varied airflow was obtained when the pneumotachometer was placed in the expiratory air line. It is not known how much variation in power-supplied flow occurs during the inspiratory phase.

It was noticed during inspiration that valve C (figure 1) remained nearly motionless. The pneumotachometer was moved between valve C and the blower. These recordings showed that when the blower was off, the major portion of inspiratory flow occurred through the channels of the blower rather than valve C at low inspiratory flows (< 150 liters/min). At higher flows, the path of least resistance would be taken.

The flow produced by the power-assist unit was accompanied by a positive mask pressure of 14 mm H₂O when compared with atmospheric pressure. This pressure is produced by the expiratory resistance of the mask. For the sake of simplicity, it was assumed in the following calculations that the blower-supplied airflow and pressures were constant during the breathing cycle rather than showing variations.

The relationships between inspiratory flow and pressure with and without the power-assist system are shown in figure 2. Resistance was measured as the ratio of peak or maximal pressure to maximal flow in a series of single breaths. Maximal values were used because they do not require careful measurement of lag times in the system.

The various mask resistances can be described mathematically using the following relationships. If we let

- R = resistance of mask
- P = pressure in mask compared with atmosphere
- F = flow through mask
- i = subscript for inspiration
- e = subscript for expiration
- b = subscript for fraction supplied by power assist
- p = subscript for fraction supplied by subject

then the general relationship describing resistance is:

$$R = \frac{P}{F}$$

During inspiration, without the power-assist system, the resistance, R_i , was measured as the ratio of the peak inspiratory pressure, P_i , to the peak inspiratory flow, F_i (figure 2). Similarly, the expiratory resistance, R_e , was measured as the ratio of the peak expiratory pressure, P_e , to the peak expiratory flow, F_e (figure 3).

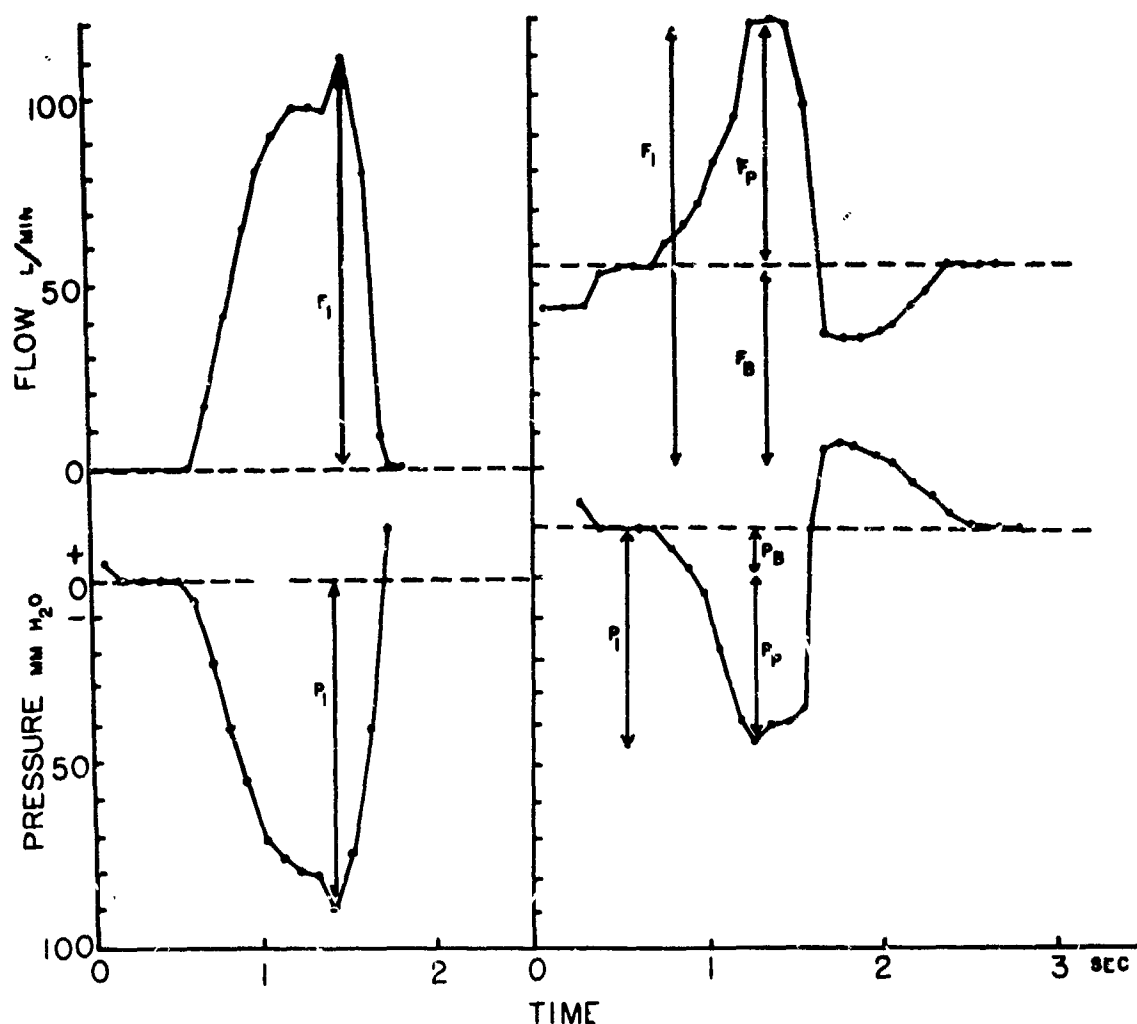


Figure 2. Inspiratory Flow and Pressure Relationships of M17A1 Mask With and Without Power-Assist Unit

Left side illustrates simultaneous recording of inspiratory flow and pressure of M17A1; the dashed line indicates 0 flow and pressure. Right side illustrates recordings of M17A1 with power-assist unit on; the dashed lines indicate the flow and pressure levels produced by the power-assist unit, i.e., baseline with no breathing. The flow and pressure curves after 1.6 seconds (right side) illustrate the response of the inspiratory flow and noseclip pressure to expiration. The following symbols are used: F = flow through mask; P = pressure in mask; i = subscript for inspiration; b = subscript for power-assist supplied fraction; and p = subscript for subject supplied fraction.

When the power-assist unit was turned on, the inspiratory flow below 56 liters/min was supplied by the blower, F_b , at no resistance to the wearer; inspiratory flow through the filters above 56 liters/min was supplied partially by the blower, F_b , and partially by the work of the breathing muscles, F_p (figure 2).

The internal mask pressure during inspiration also has two components: P_b , which is a positive mask pressure compared to atmospheric pressure and is produced by the blower against the expiratory resistance; and P_p , which is negative compared to atmospheric pressure and is produced by the breathing muscles during inhalation.

The inspiratory resistance, as it affects the wearer, is less with the blower turned on and was measured as:

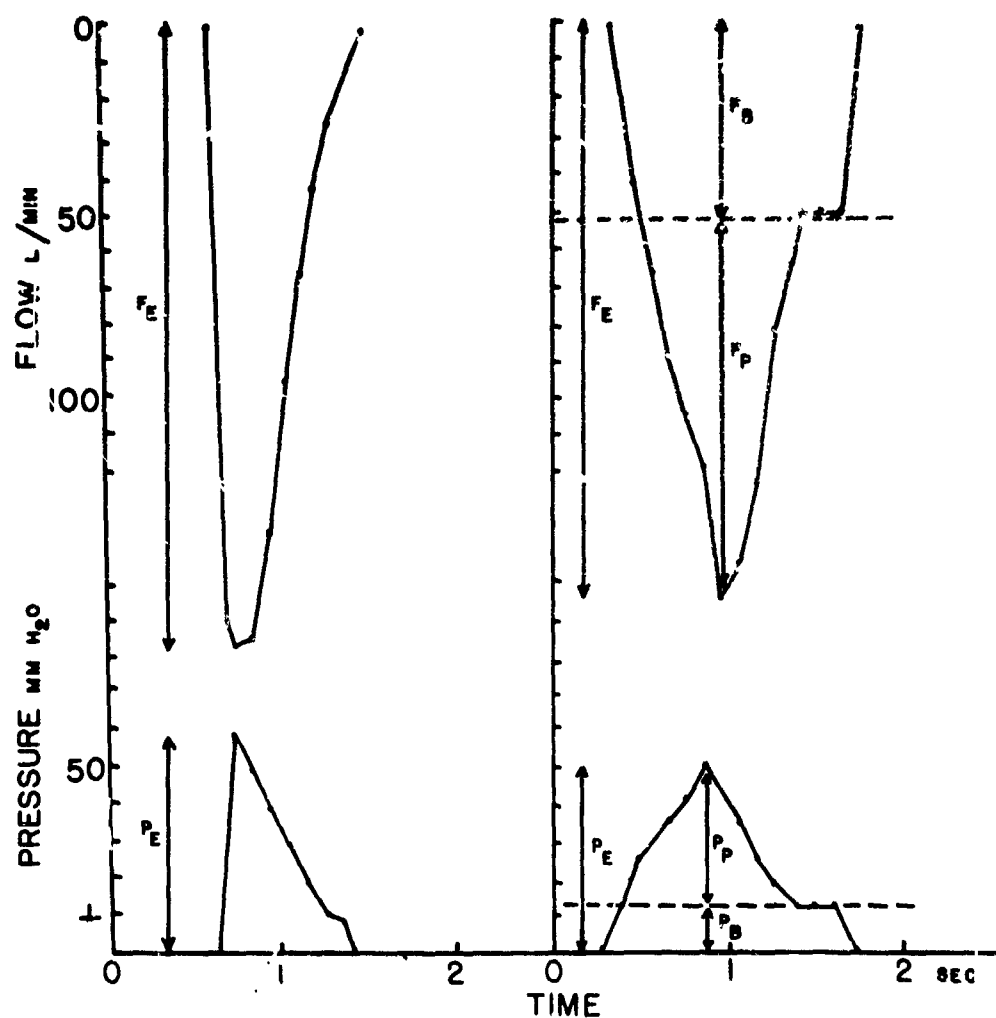


Figure 3. Expiratory Flow and Pressure Relationships of M17A1 Mask With and Without Power-Assist Unit

Left side illustrates simultaneous recording of expiratory flow and pressure of M17A1. Right side illustrates recordings with power-assist unit on. Expiration begins at 0.2 seconds and continues until 1.4 seconds, where a slight pause between inspiration and expiration is noted as leveling followed by the beginning of an inspiration. The dashed lines are levels produced by the power-assist unit. The following symbols are used: F = flow through mask; P = pressure in mask; e = subscript for expiration; b = subscript for power-assist supplied fraction; and p = subscript for subject supplied fraction.

$$R_i = \frac{P_p}{F_i}$$

or the ratio of the negative inspiratory pressure to the total inspired airflow (figure 2). At inspiratory airflows of 56 liters/min and less, P_p is no longer negative, and the resistance of the mask system becomes 0.

Expiratory resistance, like inspiratory resistance, was measured at the peaks of flow and pressure (figure 3). With the power-assisted unit on, the subject expires against the blower-supplied pressure plus the pressure of expiration so that:

$$P_e = P_p + P_b$$

The flow measured by the expiratory pneumotachometer is the sum of the blower-supplied flow and expired flow from the lungs and can be represented by

$$F_e = F_b + F_p$$

The resistance to the wearer involves moving expired air, F_p , against pressure in the mask produced by the blower, P_b , in addition to the pressure associated with his expiration P_p . Thus, the expiratory resistance can be described as:

$$R_e = \frac{P_b + P_p}{F_p}$$

Both the inspiratory and expiratory pressure-flow curves of the power-assist mask are compared in figure 4. The resistances of the power-assisted unit are compared in the table at the currently accepted standard airflow for measuring resistance of 85 liters/min.

D. Discussion.

The major concern about power-assisted breathing is whether it will improve a man's performance over that with present equipment. Several factors besides resistance have been identified that modify performance in protective masks.^{5,6} It would appear superficially that the power-assist concept might improve performance by reducing "resistance" and discomfort and increase evaporative cooling. Whatever advantage is gained has to offset the disadvantage of the additional carried weight imposed by the power source and blower.

If we look at the inspiratory resistance, it is certainly lowered; but the expiratory resistance is increased by the new system. The early work of Silverman et al.⁷ and a later work of Craig, Blevins, and Cummings⁸ indicated the possibility of critical expiratory resistance in limiting work performance. However, the testing of two expiratory valves in series did not decrease treadmill walking times in the studies of Craig, Blevins, and Froehlich⁶ and running time with trained subjects in Van Huss and Heusner's⁹ studies.

The positive aspects of the power-assist concept mentioned earlier may be outweighed by the negative aspects of additional weight of batteries and blower and tubing adaptations and increased expiratory resistance.

⁵Cummings, E. G. Interim Summary Report. Effects of Non-CB Stresses on the Wearer of the CB Protective Ensemble. Part 1: Identification of Factors Which Modify Performance of Men Wearing CB Equipment. May 1970. UNCLASSIFIED Report.

⁶Craig, F. N., Blevins, W. V., and Froehlich, H. L. EATR 4535. Training to Improve Endurance in Exhausting Work of Men Wearing Protective Masks. August 1971. UNCLASSIFIED Report.

⁷Silverman, L., Lee, G., Yancy, A. R., Amory, L., Barney, L. J., and Lee, R. C. Fundamental Factors in the Design of Respiratory Protective Equipment. OSRD Contract OEMsr 306. Harvard School of Public Health. May 1945. UNCLASSIFIED Report.

⁸Craig, F. N., Blevins, W. V., and Cummings, E. G. Exhausting Work Limited by External Resistance and Inhalation of Carbon Dioxide. J. Appl. Physiol. 29, 847-851 (1970).

⁹Van Huss, W. D., and Heusner, W. W. Michigan State University. Final Report. Contract DA 18-035-AMC-25 (A). The Respiratory Burden of the Field Protective Mask. September 1965. UNCLASSIFIED Report.

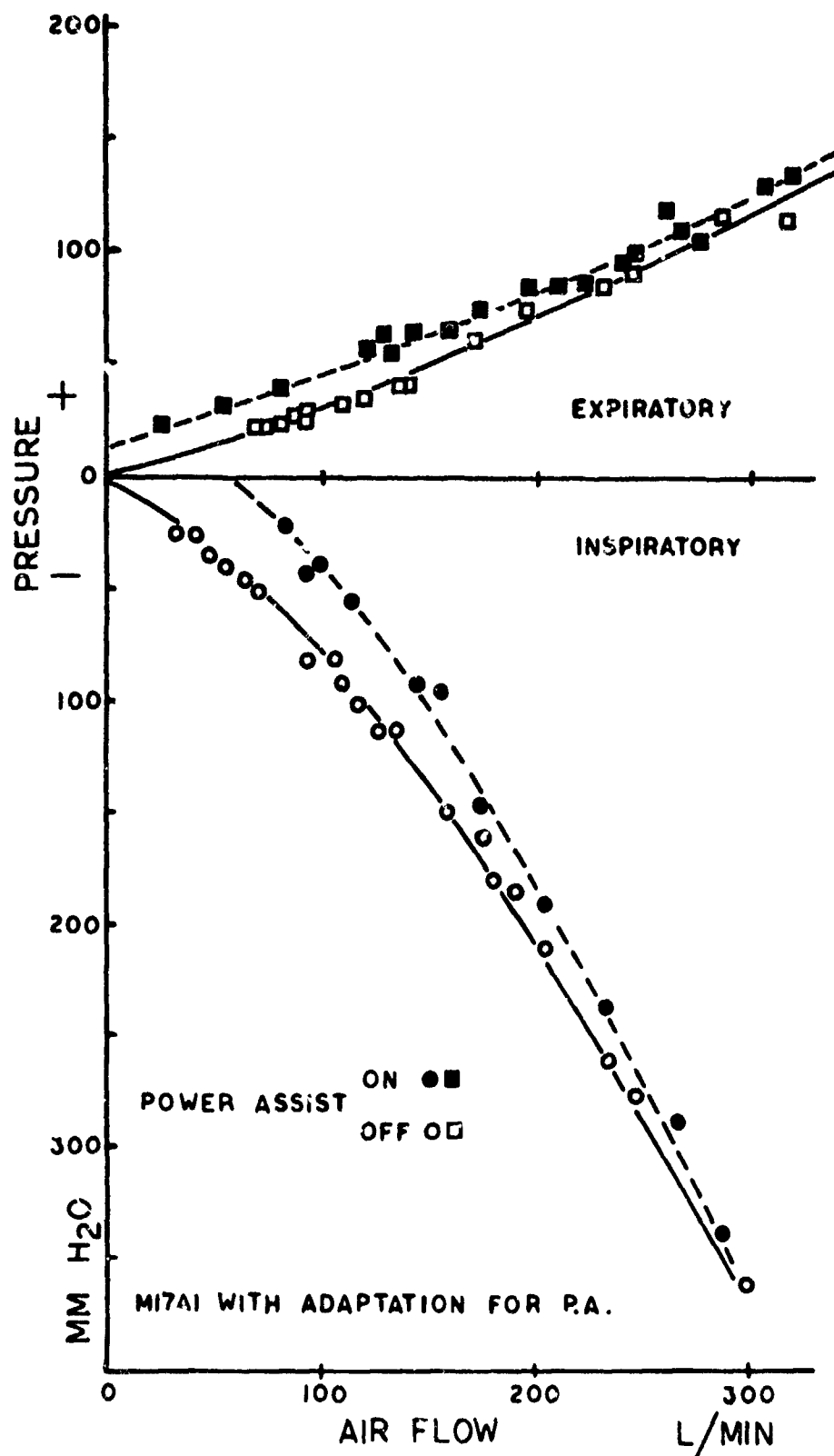


Figure 4. Pressure and Flow Diagrams for the M17A1 Mask With and Without Power-Assist Unit

Expiratory and inspiratory pressures were measured from the nosecup of the mask; airflows were measured in the inspiratory and expiratory lines.

Table. Pressure Characteristics of Masks at 85 Liters/Minute Flow*

Mask	Pressure, inspiratory	Pressure, expiratory	Source
	<i>mm H₂O</i>		
M9	75	22	Production standard
M17	55	23	Production standard
M17A1	55	32	Production standard
Power assist	25	44	Fig 4

*Resistance, expressed as millimeters of H₂O at 85 liters/min flow, is used in protective design as a common convention. The definition was made by Silverman, L., Lee, G., Yancy, A. R., Amory, L., Barney, L. J., and Lee, R. C. *In Fundamental Factors in the Design of Protective Respiratory Equipment*. Contract OEMsr 306. May 1945. UNCLASSIFIED Report. It is also used by the U.S. Bureau of Mines, Procedure for Testing Gas Masks for Permissibility, Schedule 14D, May 9, '935.

III. PART II, THE SUBJECTIVE PREFERENCE FOR AIRFLOWS OVER THE FACE.

A. Purpose.

A factor to be considered in the design of a power-assisted device is the airflows that would be subjectively preferred or tolerated. These were determined to establish limits for the engineering ranges of subjectively tolerated airflows. Subject objections to a flow of air and its accompanying pressure over the face, including difficulty with expiration and inspiration, pain in or over the eyes, or other feelings of generalized discomfort, could be expected. The object was to define these limits, particularly at neutral temperatures.

B. Materials and Methods.

The inspiratory ports of an M17A1 protective mask were connected to a common inspiratory line by a Y-tube. This common line was in turn connected to an inspiratory valve, a three-way on-off valve, a flowmeter, and a three-way valve to adjust flow supplied by the output or pressure side of a vacuum cleaner used as a blower. This is shown in figure 5.

The subjects sat on one side of a partition so they could not observe the flowmeter. They could hear the motor of the vacuum cleaner, which was left running continuously while airflows were adjusted. To begin each test, the subject was asked if he were ready, and then the unknown flow was directed into the mask for 1 minute. The subject was then asked to fill out the airflow evaluation form (figure 6).

Testing lasted for 2 days. On day 1, the subjective evaluation of 250, 200, 150, and 100 liters/min was tested; on day 2, the subjects evaluated flows of 150, 125, 100, and 75 liters/min. Each man was exposed to all airflows 1 day before the tests began so he would know what to expect.

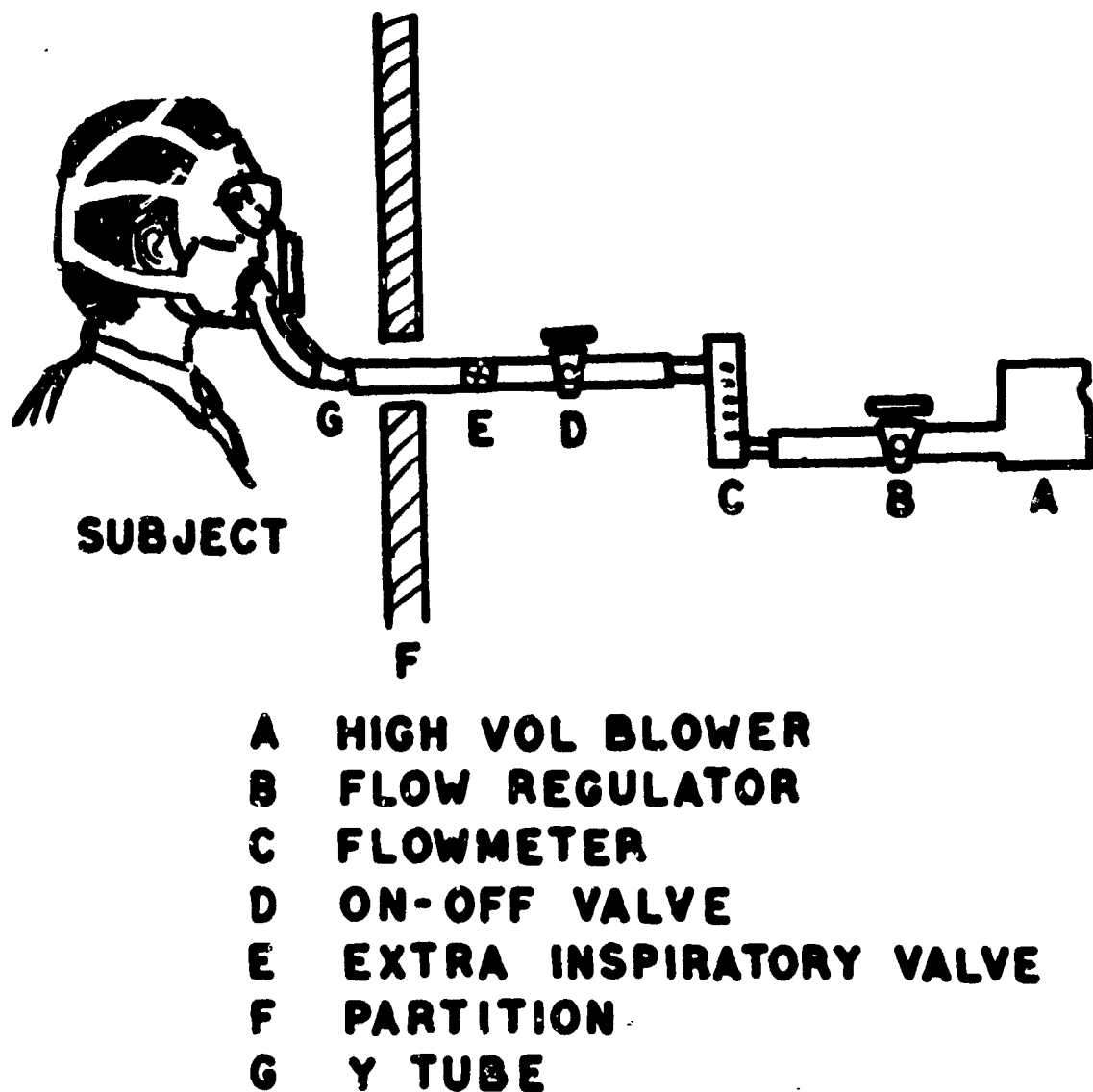


Figure 5. Equipment for the Subjective Evaluation of Airflows

C. Results.

The results are shown in figure 7. Here, the severity of subject responses is plotted against air flowing through the mask. The top three topics for discrimination, namely, difficult breathing, inhalation, and expiration, are somewhat redundant but were used in case there was any comprehension difficulty with subjects. The category of "mask movement" was to include leakage and bellows action. "Eyes uncomfortable" included smarting and blinking of eyes and any discomfort about the supra-orbital ridge or zygomatic area. "General discomfort" was to be a general reaction of disfavor toward the mask and airflows and could cover any unexpected complaint.

These comments were mainly of a negative viewpoint. At the bottom of the form, subjects were asked to write whether they found any of the airflows pleasing. One man did at 100 liters/min.

NAME _____

TEST _____

Did you experience any of the following problems at this air flow?

	None	Mild	Severe
Difficulty breathing			
Difficulty inhaling			
Difficulty exhaling			
Mask moving on face			
Difficulty with eyes			
Discomfort			

Figure 6. Airflow Evaluation Form

The comments indicate that the most severely noticed condition was difficulty with expiration, followed by discomfort near the eyes. The discomfort ratings were all low at airflows of 75 liters/min, and 100 liters/min. was well tolerated.

D. Discussion.

Because the questionnaire was negatively directed, it may be thought to have emphasized the "bad" side of power-assisted breathing. Yet it served the purpose of giving a range of tolerated airflows, and its negativity gave the conservative limit. Five of the six subjects described the 50 liters/min as pleasant but mild when asked; the other objected to the air flowing over his eyes. Thus we conclude that, based on subjective preference, airflows of 75 to 100 liters/min would be well tolerated.

If the airstream were colder, as found in the Arctic areas, then the preferred airflow might be still less. If the airstream were warmer, as found in the Tropics, then subjects might prefer higher airflows.

Because the higher airflows were found to be objectionable, the engineering resources should be concentrated at providing a power-assisted breathing continual mode at flows of 75 to 100 liters/min (2.6 to 3.5 cfm) if the concept is developed.

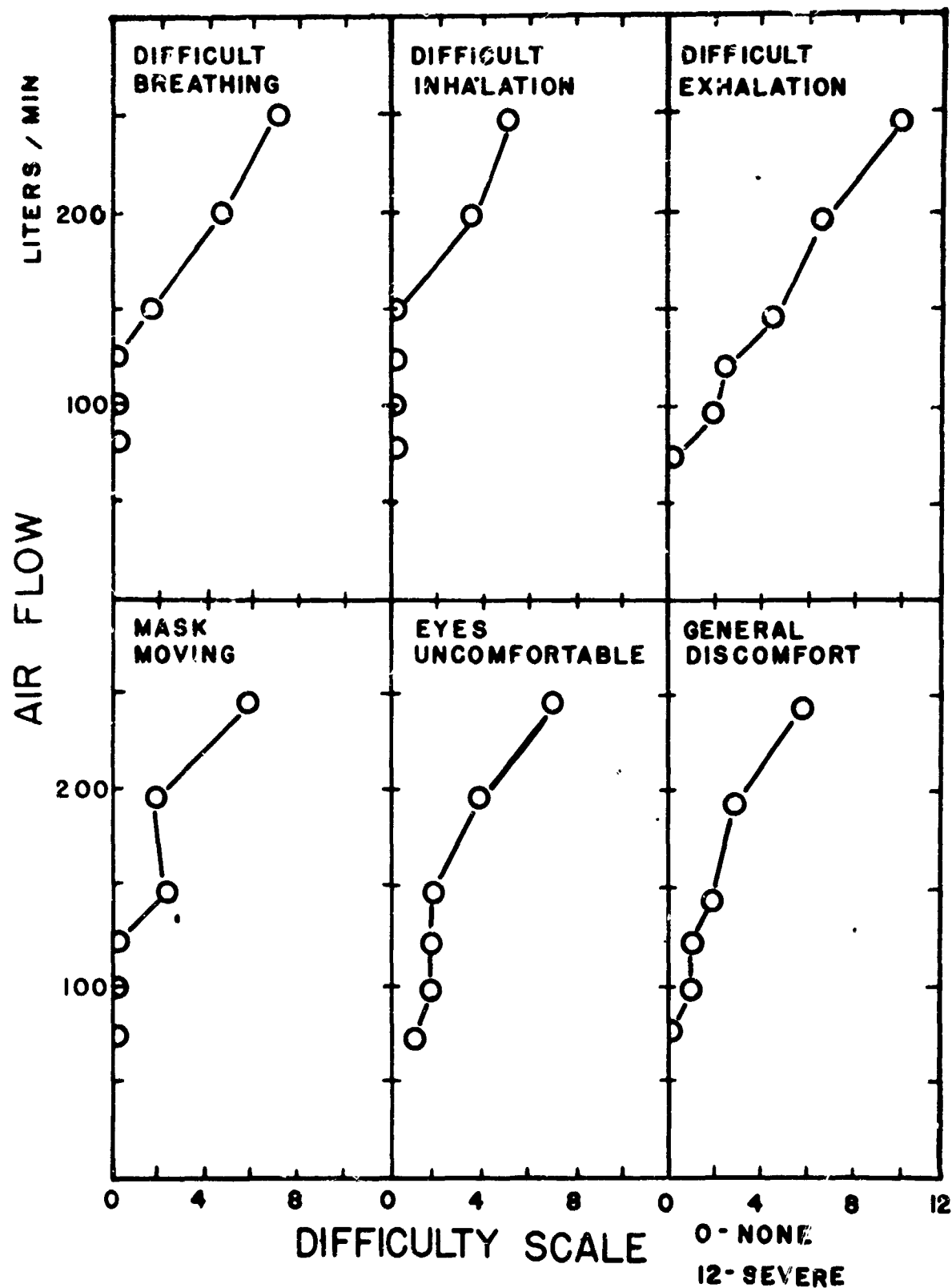


Figure 7. The Subjective Evaluation of Airflows Over the Face

The difficulty scale is based on subjective response and is arbitrary

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